"Nanotechnology Directions within the Dimensional and Mechanical Metrology Programs of the NIST Manufacturing Engineering Laboratory"

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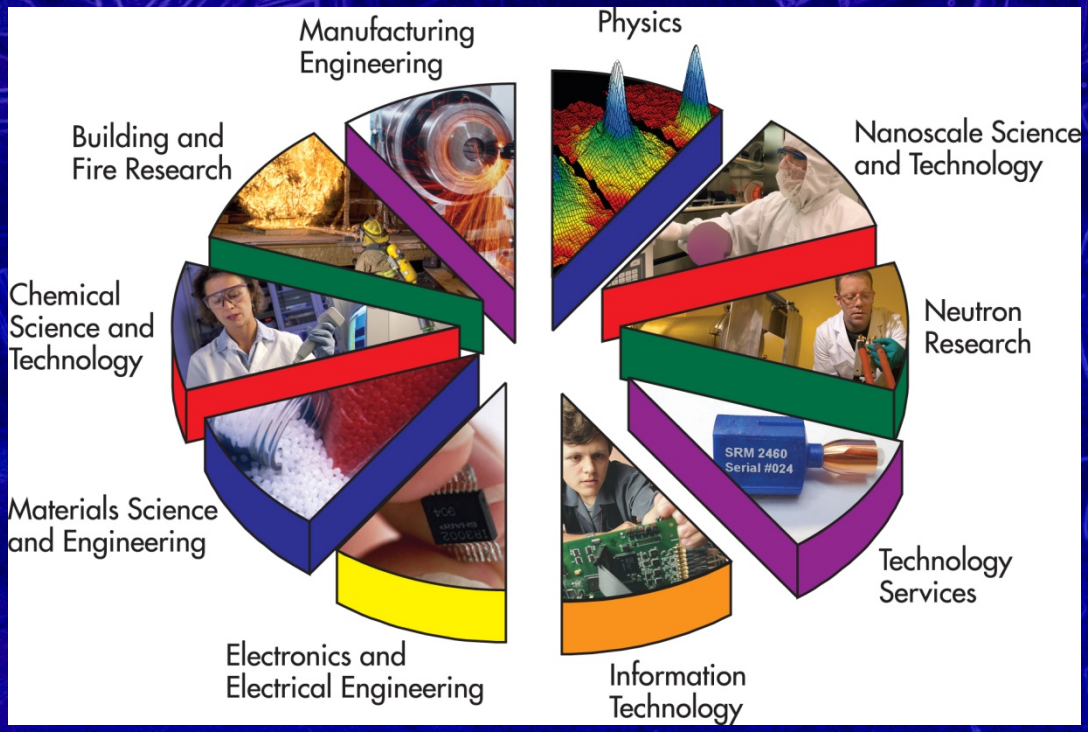
February 6, 2008

NIST National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

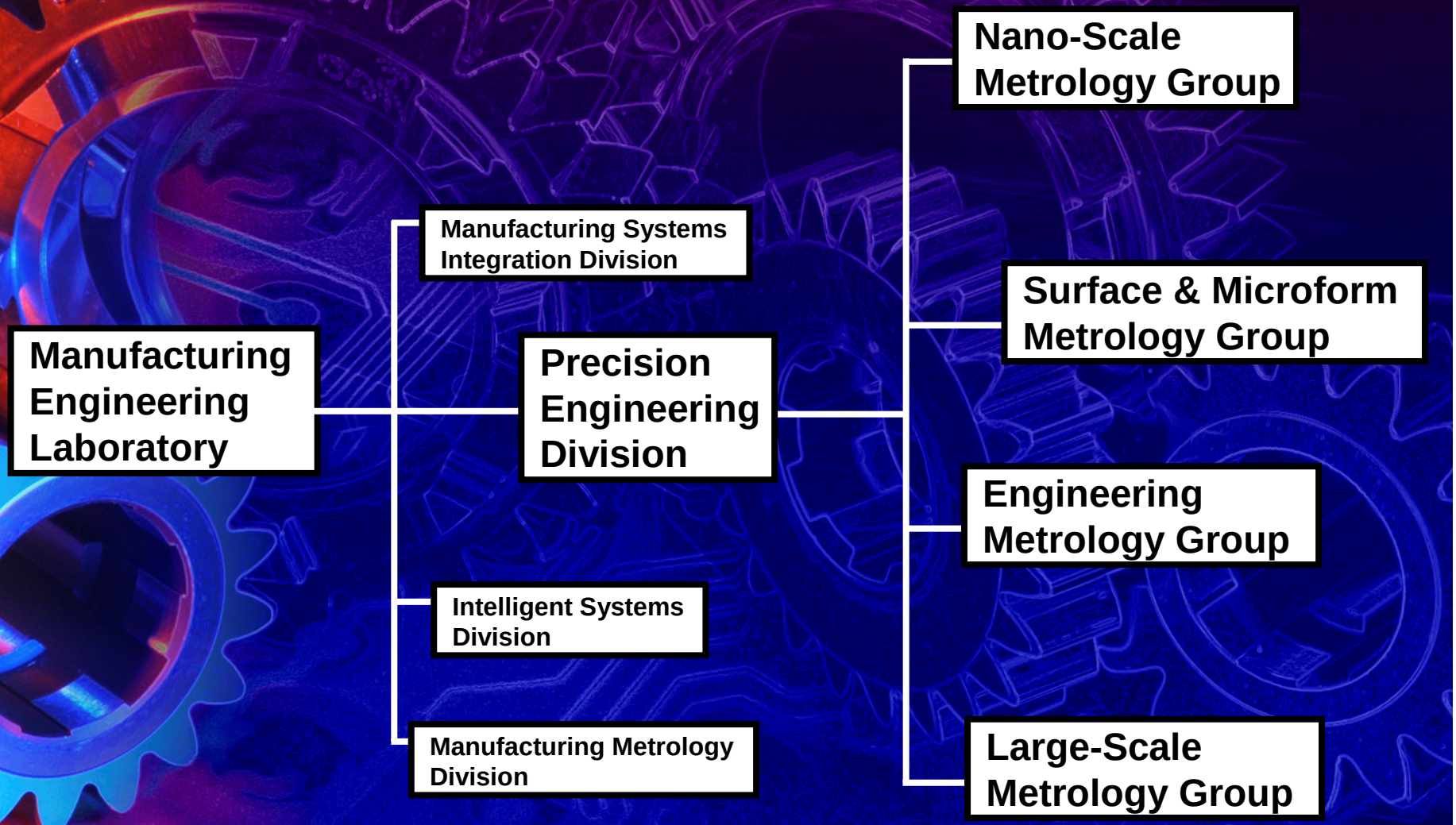
MEL innovation & productivity

Background

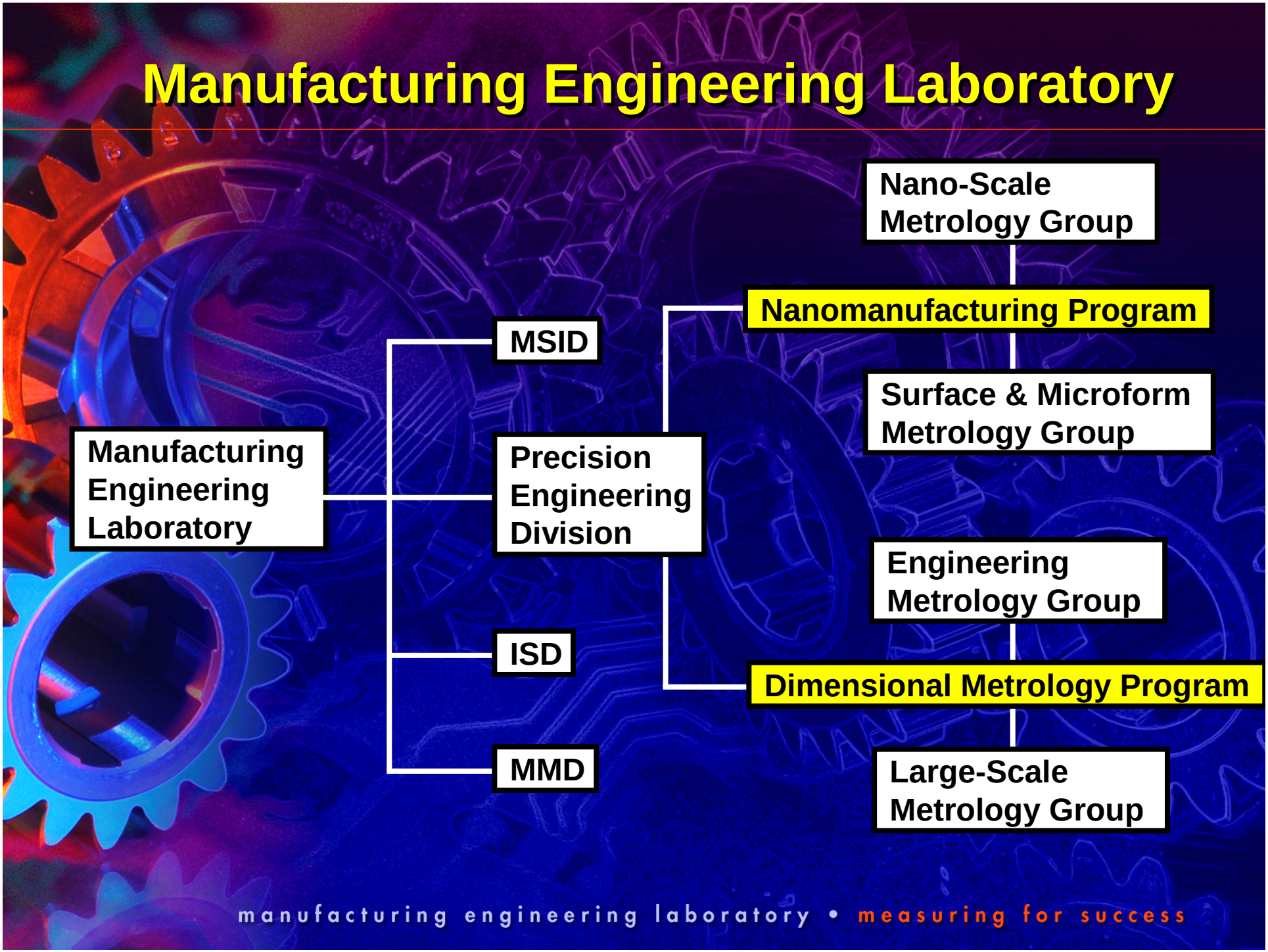
- NIST is the U. S. National Measurement Laboratory
  - Promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.



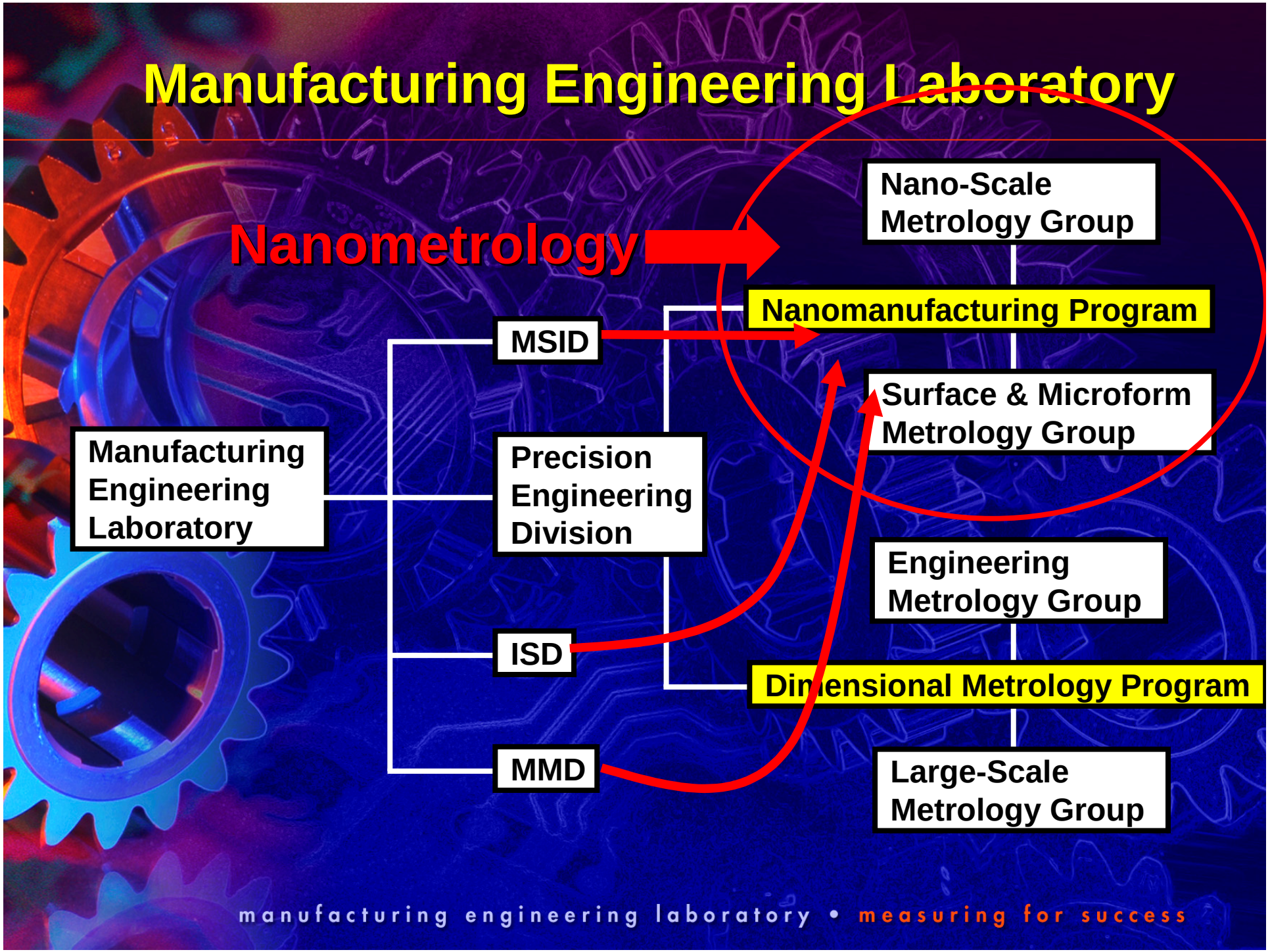
•Manufacturing Engineering Laboratory



Manufacturing Engineering Laboratory



Manufacturing Engineering Laboratory



Nanotechnology and Nanomanufacturing

- Nanotechnology is the frontier of innovation and is one of the most dynamic growth areas in the U. S.
  - Predicted by NSF to become a trillion dollar business
  - Large U. S. Federal government investment
- Nanometrology is needed by nanotechnology and nanomanufacturing more than any other prior technology.
  - NIST has been tasked by the NNI as the lead agency for Instrumentation, Metrology and Standards
  - NIST is co-lead with NSF on Nanomanufacturing.

Approximate 2005 Nanotechnology Spending

World-wide government spending has been (≈$4.6 billion):

- $1.7 billion (36%) in North America, almost entirely accounted for by the U.S.
- $1.7 billion (36%) in Asia, dominated by Japan
- $1.1 billion (26%) in Western Europe, led by Germany
- $100 million in the rest of the world

Established corporations spent (≈$4.52 billion):

- $1.9 billion (42%) was in North America
- $1.7 billion (38%) was in Asia
- $850 million (19%) was in Europe
- $70 million (2%) was in the rest of the world

“Flat-world” Nanotech Activities

- Fundamental knowledge gaps emerging
  - Materials
  - Measurements
  - Instrumentation
  - Standards
  - Environmental Health and Safety (EHS)
- Each National Measurement Institute (NMI) has activities in Nanotechnology
- Primary needs are instrumentation, metrology and standards

Problem

- Much of the measurement infrastructure currently used by nanotechnology/industry is only evolutionary
- New potentially revolutionary metrology is needed for many applications
- Automated, operator independent instrumentation adapted to nanomanufacturing is needed
  - NNI Grand Challenge Workshop on Instrumentation and Metrology
  - IWG Instrumentation Metrology and Standards for Nanomanufacturing Workshop
- It is within NIST's Mission to develop the needed nanometrology and standards
  - NIST promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology…….

RTI International report:

Economic Impact of Measurement in the Semiconductor Industry

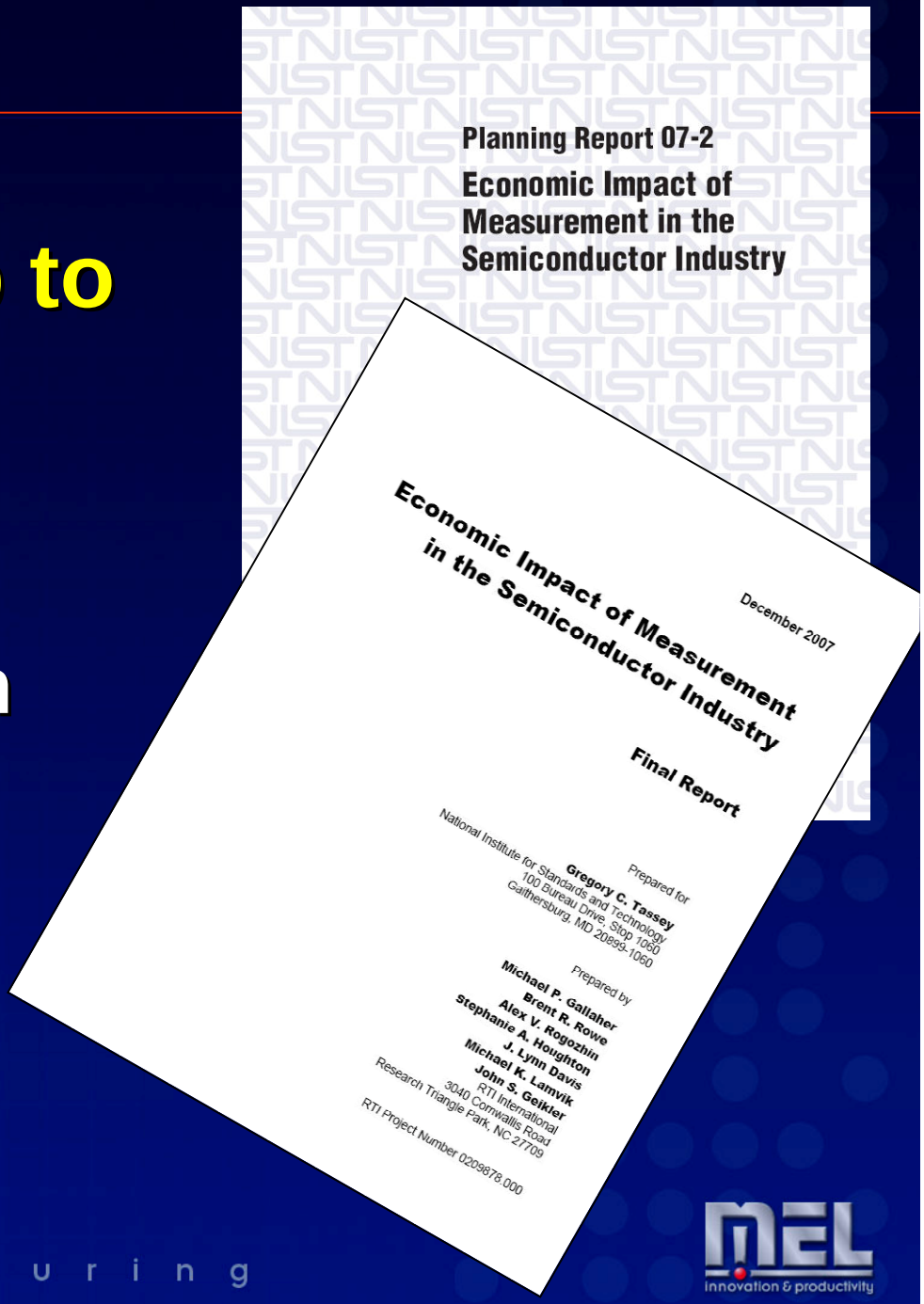
- NIST plays a leading role in developing SRMs, and most SRMs are either sold directly by NIST or are traceable to NIST standards.
- Many instrument and tool providers develop their own in-house standards to calibrate their equipment.
- These vendor-supplied standards are also usually NIST traceable.
- SRMs are used by most of the semiconductor supply chain and include the following:
  - Front-end processing
    - – thin film for transmission electron microscopy, or TEM (NIST SRM 2063a)
    - – scanning electronic microscopy, or SEM, performance (NIST SRM 2069b, 8091, and 2800)
    - – optical microscope linewidths (NIST SRM 475 and 476)
    - – implantation standards (NIST SRM 2133–2137)
    - – ellipsometry (NIST SRM 2531 and 2534)
    - – microscale dimensional measurement (NIST SRM 5001)

RTI International report:

Measurement innovations add up to big savings for semiconductors

RTI estimates that for every $1 spent on measurement, the industry as a whole saw a $3.30 return.

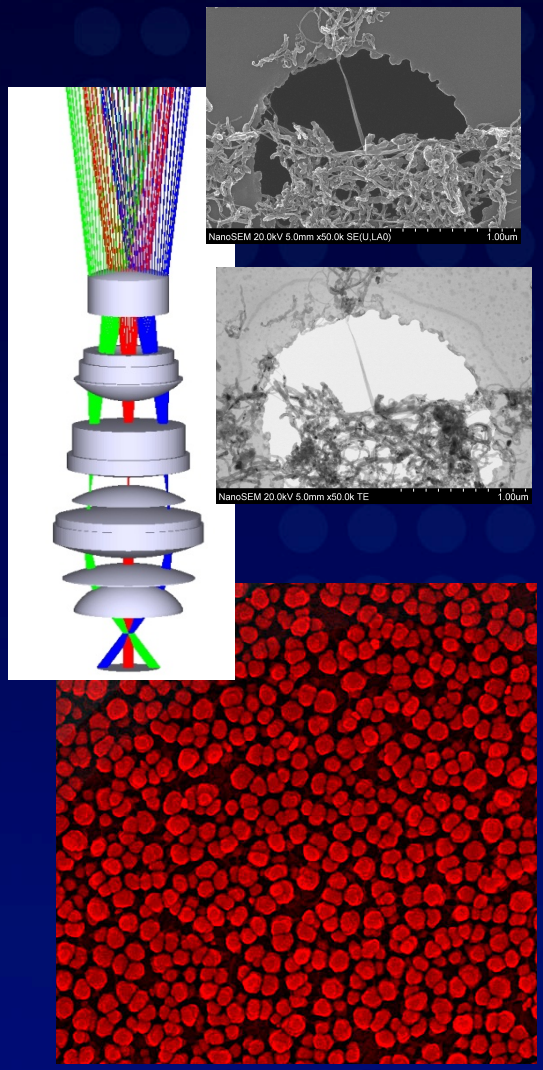
On average of 14 similar studies the ratio is $44:$1



MEL Nanometrology/Nanomanufacturing

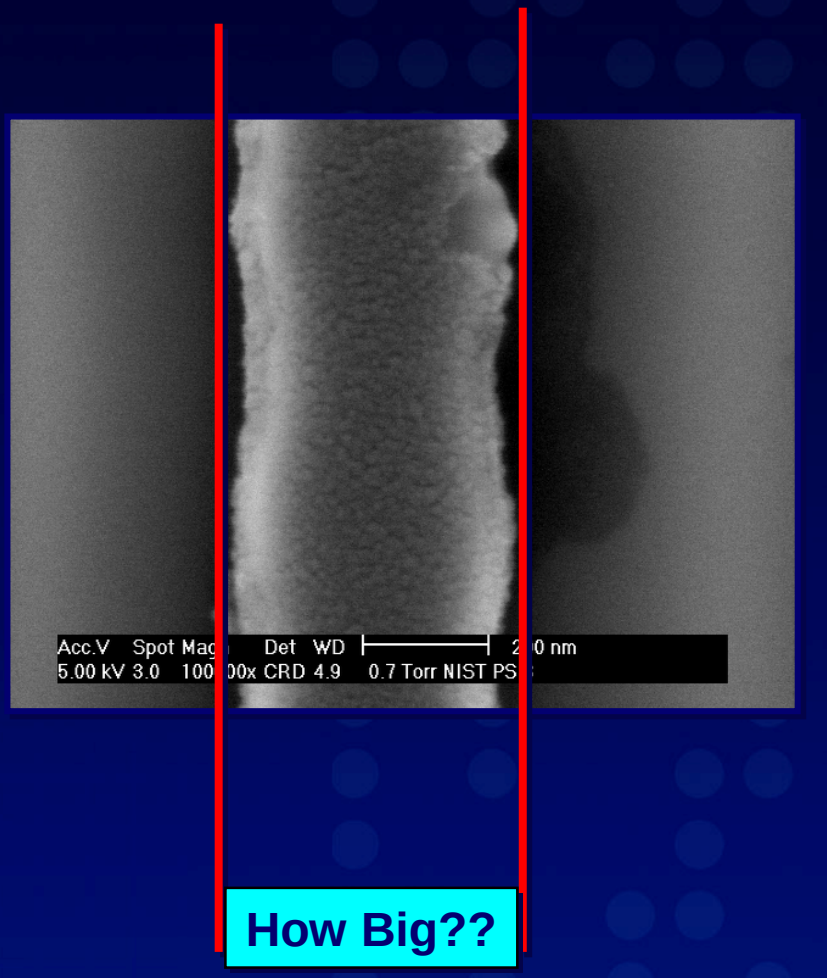
Goal:

- ***Develop and deliver timely measurements, standards, and infrastructural technologies that address identified critical U.S. industry and other government agency needs for innovation and traceable metrology, process-control and quality in manufacturing at the nanoscale.***



Technical Role in Nanotechnology

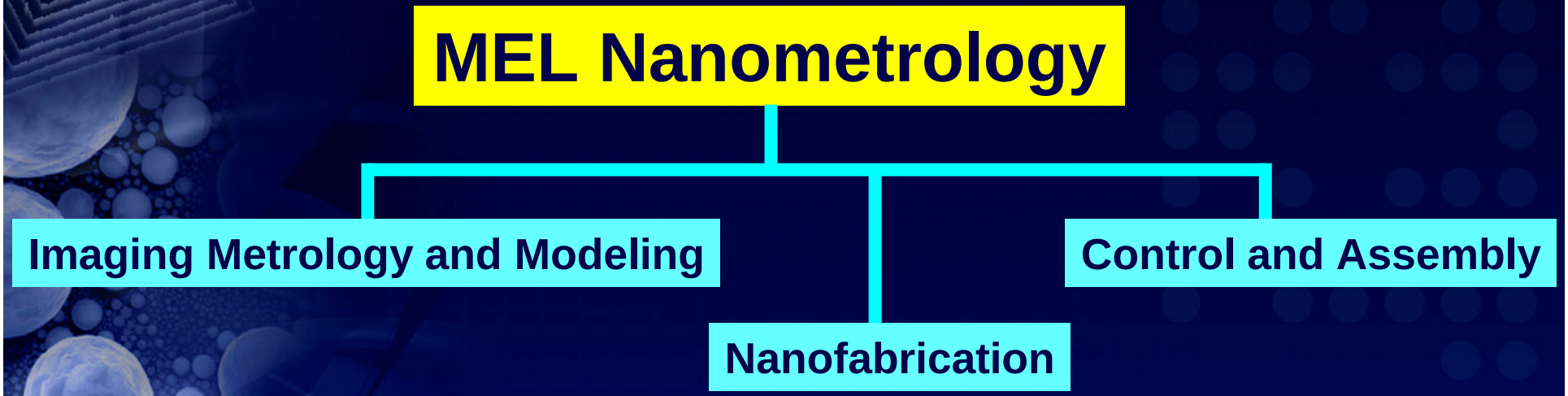
- Development of the measurement technology
  - What is measured
  - How it is measured
  - Determination of the limitations of the measurement process
- Development of new standards
- Development of uncertainty statement
  - Provides a means of comparison of metrology techniques
- Typical NIST role in metrology development



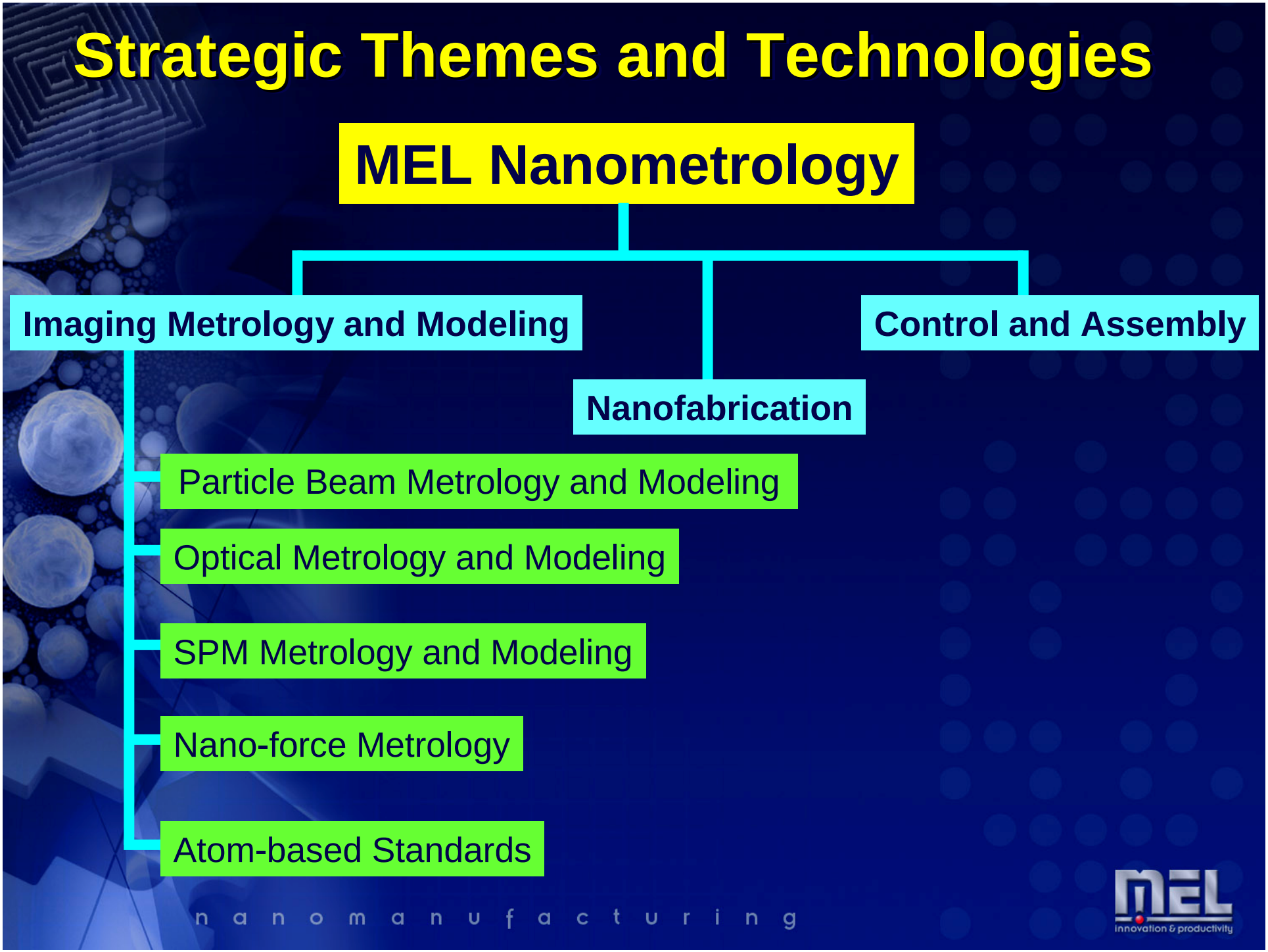
Nanometrology Strategic Vision

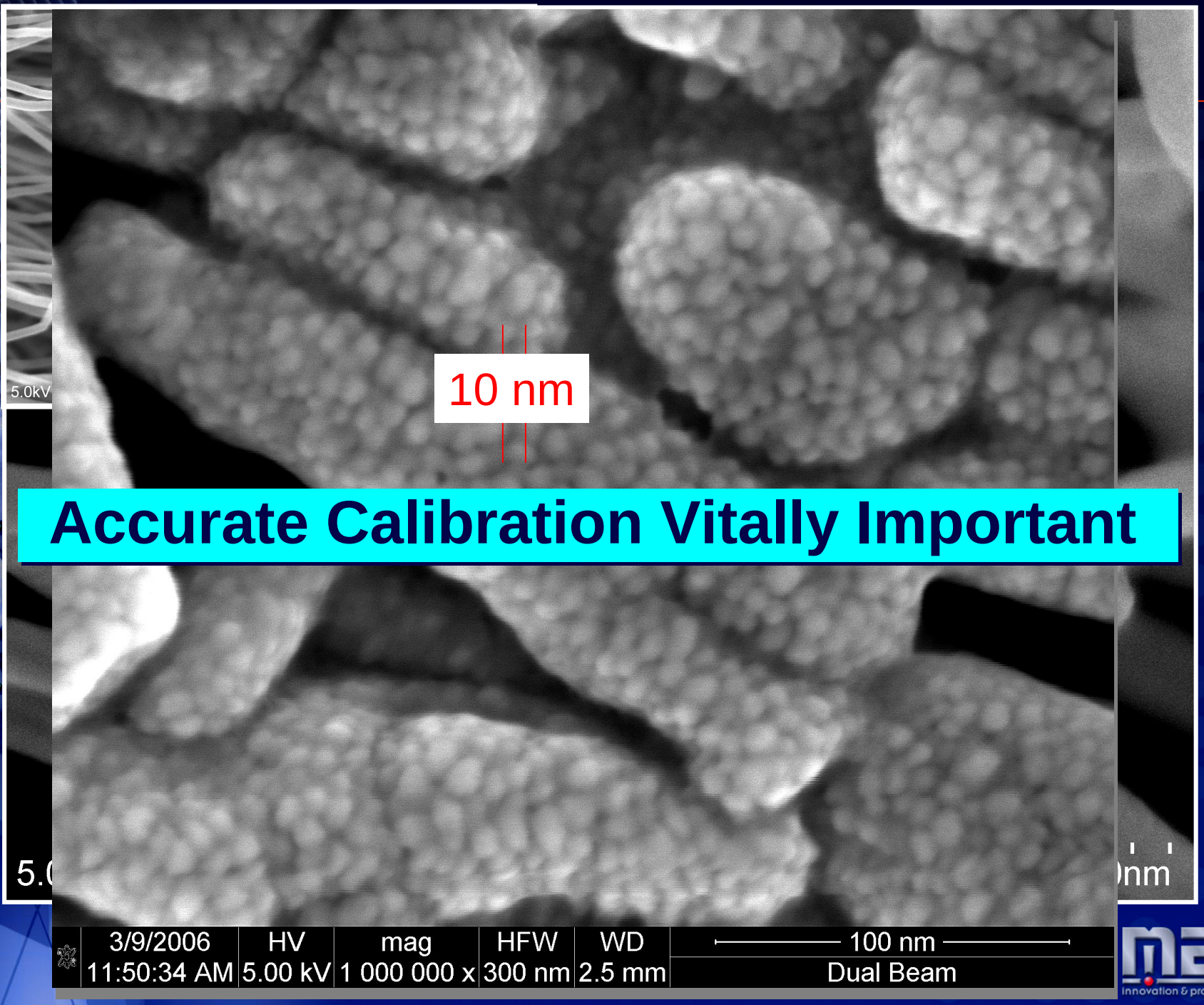
- Develop the measurement infrastructure for nanomanufacturing to reduce the barriers for technological innovation and successful commercialization of nano-based products
  - Accurate metrology that is needed by nanomanufacturing
  - Requires:
    - Fundamental scientific research
    - Theory
    - Experiment
      - agreement between theory and experiment

Strategic Themes and Technologies



Strategic Themes and Technologies





Accurate Calibration Vitally Important

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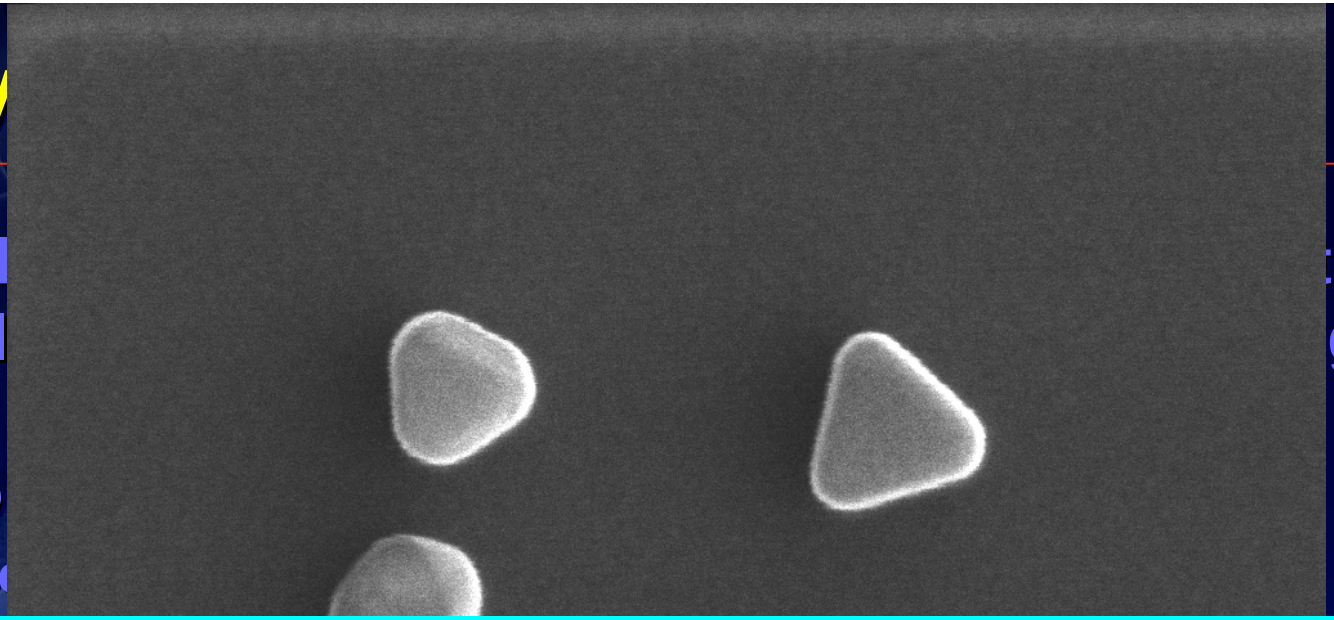

Research into Basic Contrast Mechanisms Involved with Image Formation Needed

Once that is resolved, the same issues limiting the SEM accuracy need to be tackled

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ZEISS CARL ZEISS SMT	Field Of View 600.00 nm	Detector PrimaryETDetector	Dwell Time 100.0 us	Date: 11/28/2007 Time: 2:31 PM
	Working Dist 4.5 mm	50.00 nm	Acceleration V 29985.0 V	Image Size 1024x1024

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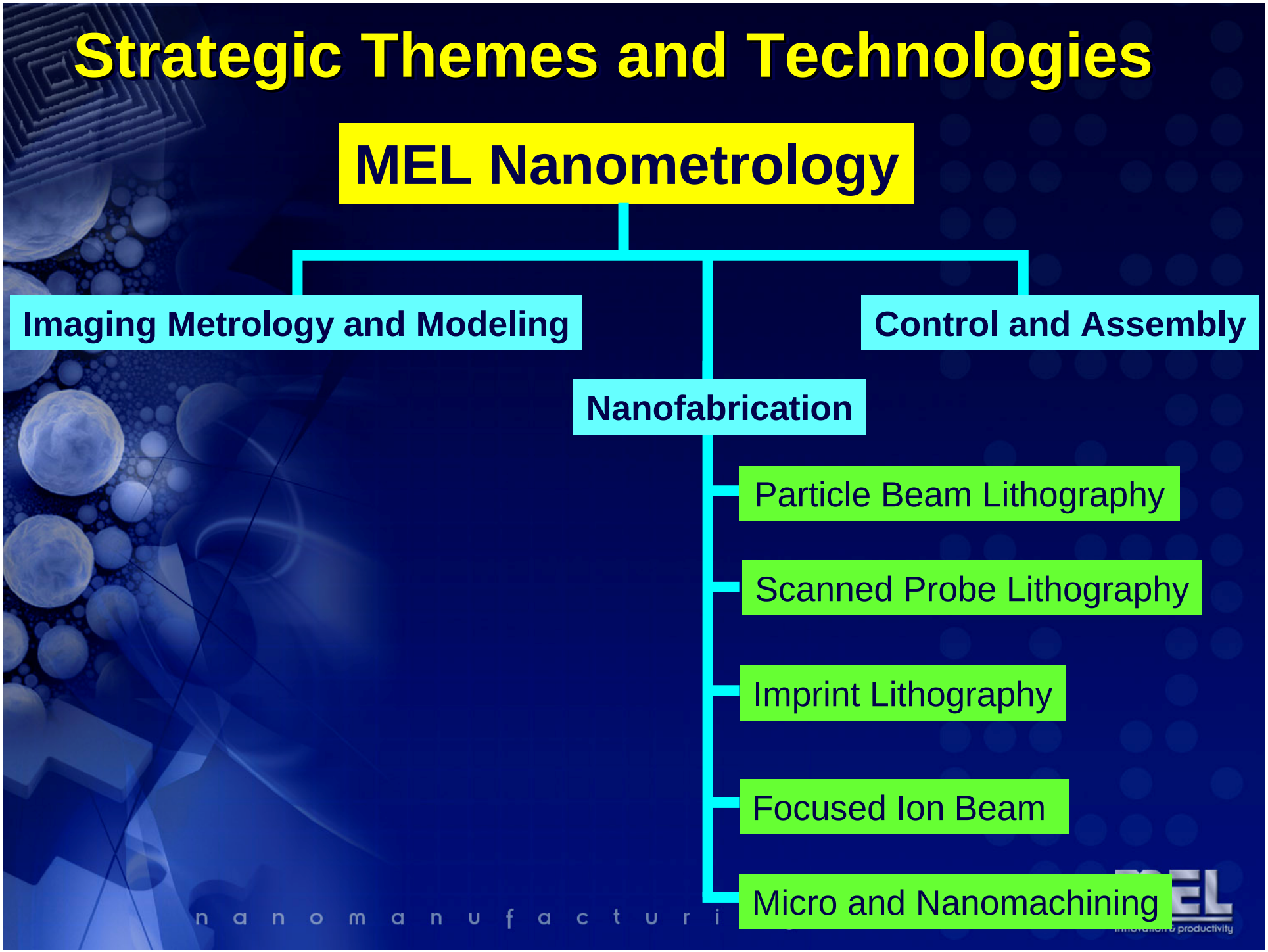
Strategic Themes and Technologies



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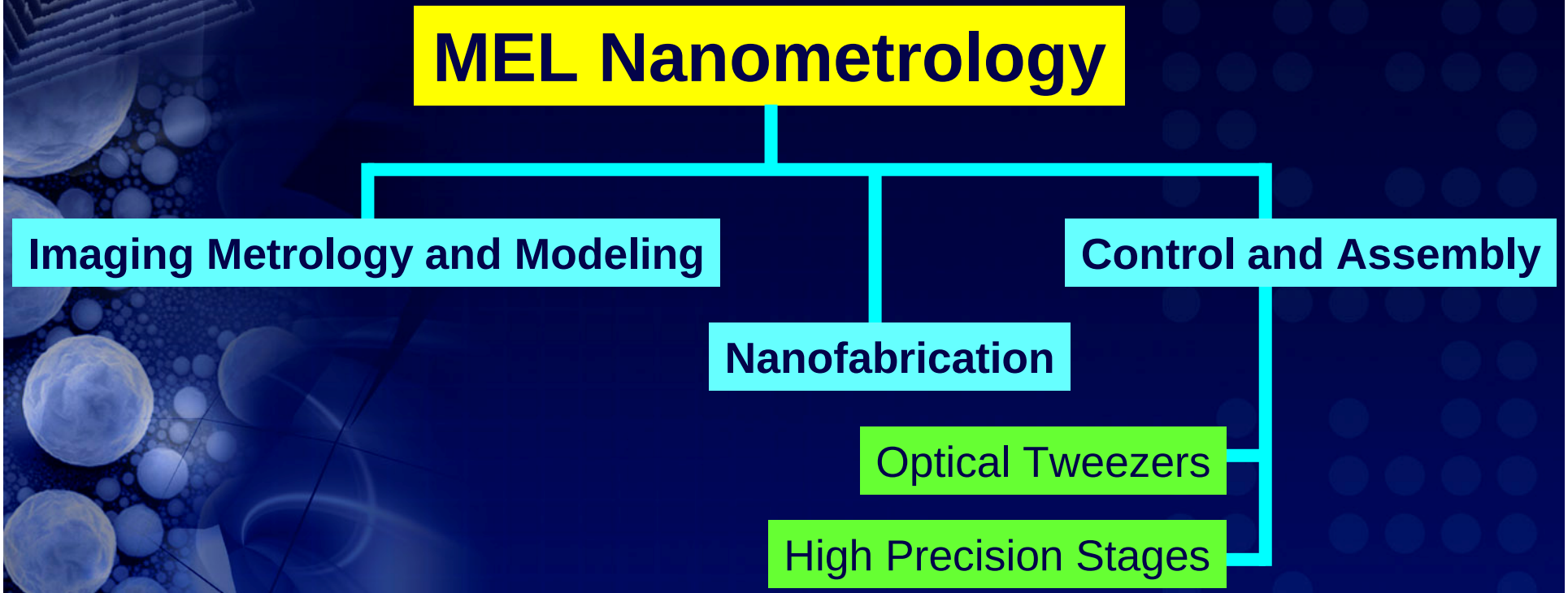

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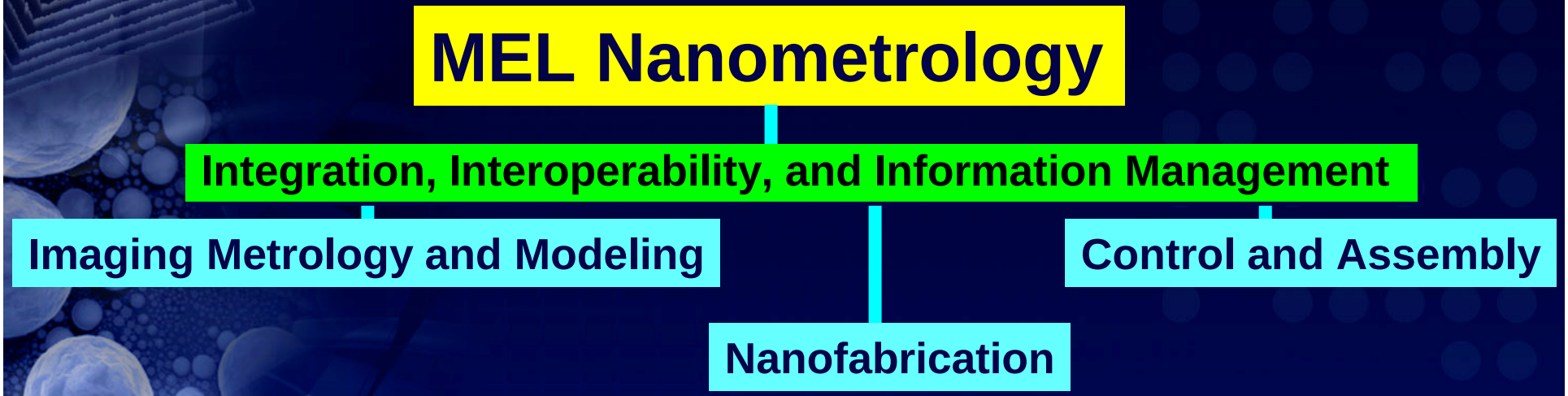
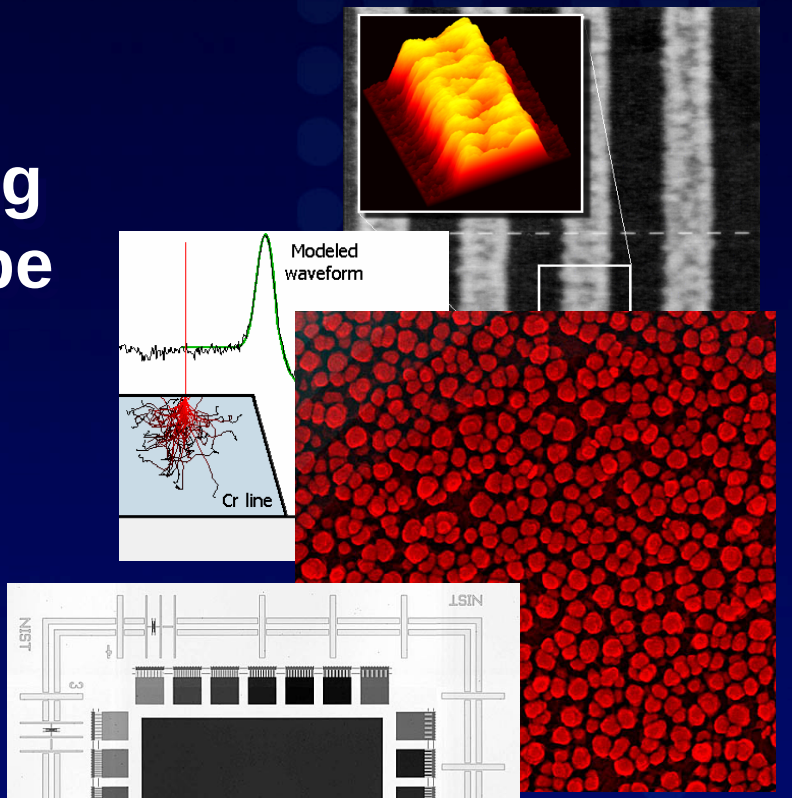
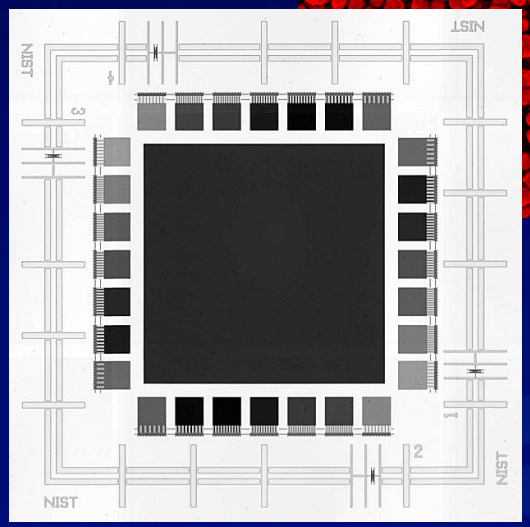


Project: Particle Beam Microscopy for Nanoscale Measurements

Goal:

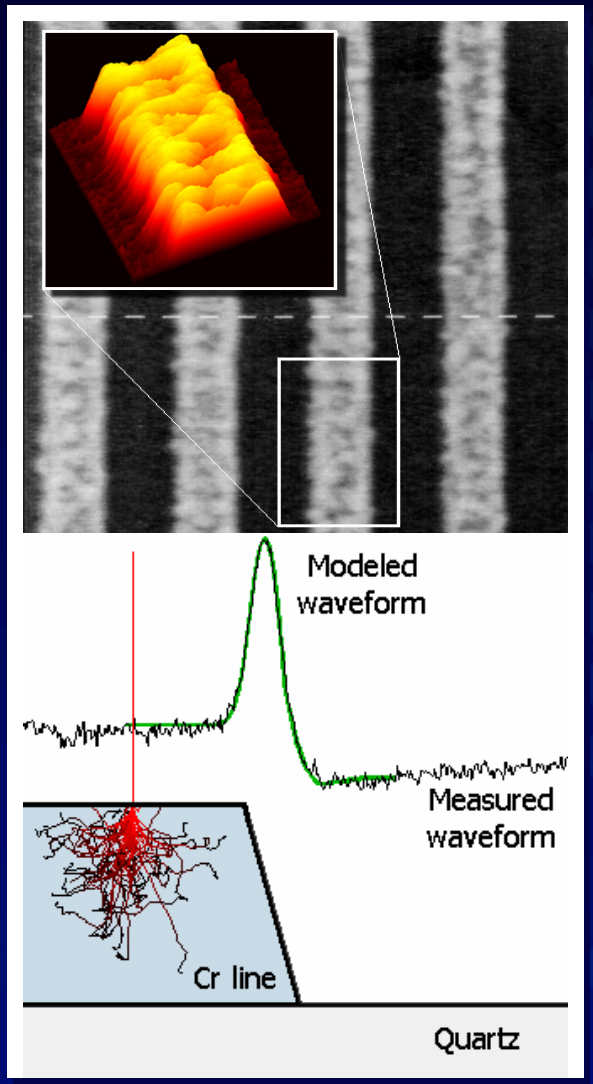
- Develop highly accurate 3-D measurement, image processing and modeling methods for shape and size measurements and relevant calibration standards with better than 1 nanometer resolution.
  - Scanning Electron Microscope
  - Helium Ion Microscope
  - Focused Ion Beam Microscope





Modeling for Accurate Metrology

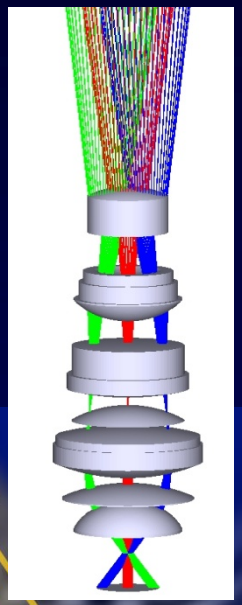
- Accuracy in production line scanning electron microscope metrology requires the development of a mathematical model to deconvolute the actual sample edge information from the SEM image collected and measured.
- Results in a factor of 3x improvement in the precision.
- Currently being used on Soluris and Hitachi instruments

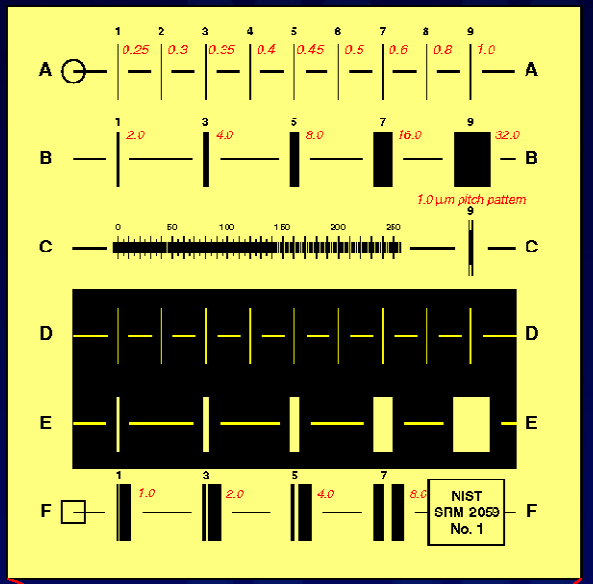


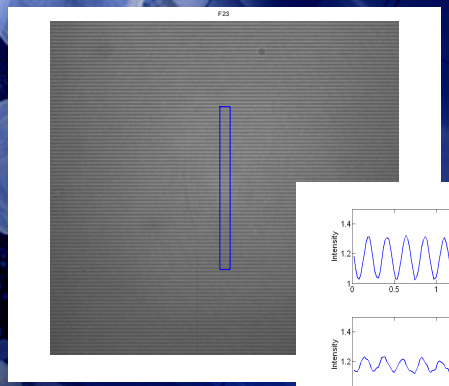
Project: Optical-based Metrology

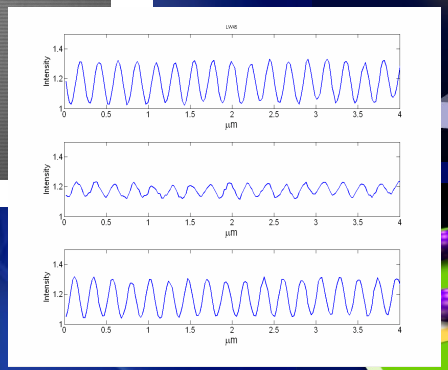
Goal:

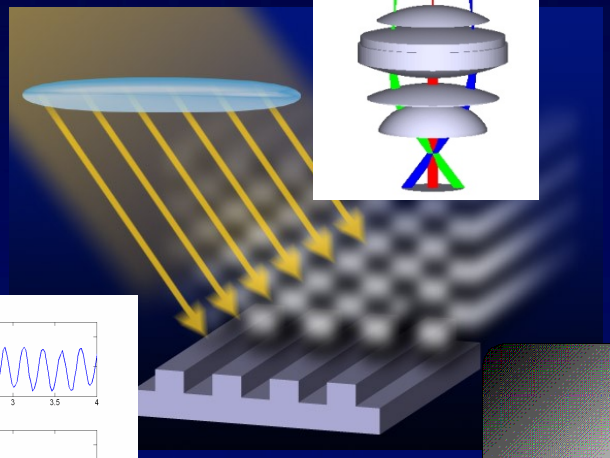
Provide world class metrology capabilities and technical leadership using optical based methods

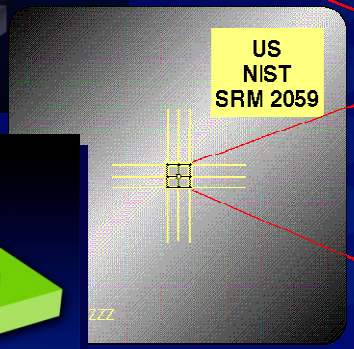


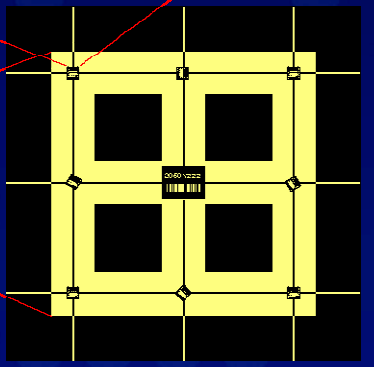


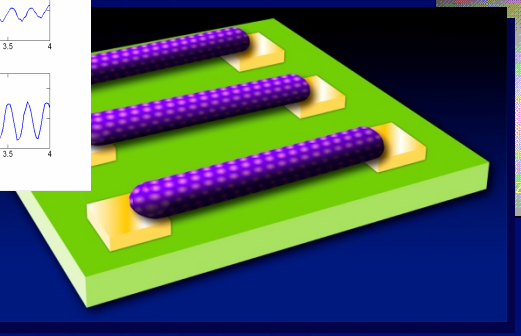










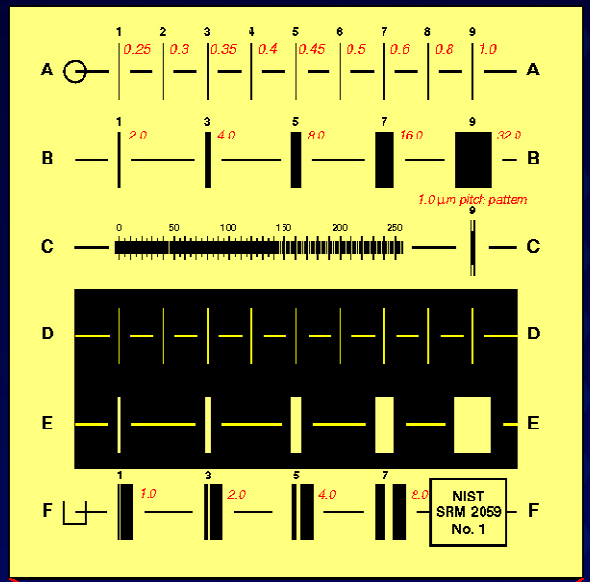


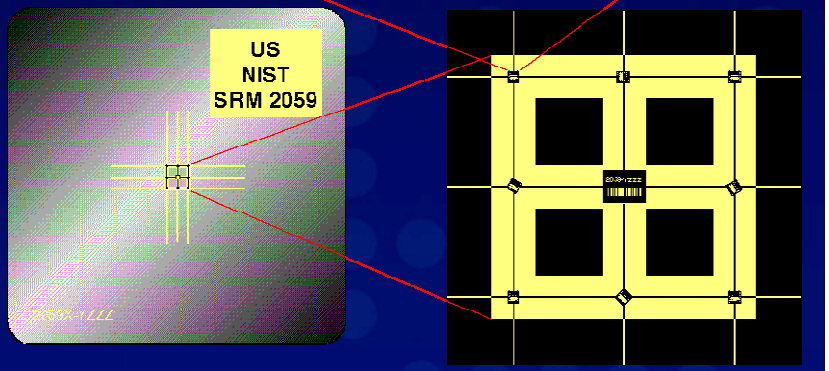
nanomanufacturing

innovation & productivity

Photomask LW Standard SRM 2059

- Calibrated SRM 2059 and traceability documentation to *Office of Standard Reference Materials* for sale to customers.
- Combination of Optical and AFM methods used.
- Optical repeatability ~3 nm.
- For isolated linewidths and spacewidths 0.25 µm to 32 µm, ISO calibration uncertainty 13-25 nm.
- For pitches from 0.5 µm to 250 µm, ISO calibration uncertainty 1-18 nm.



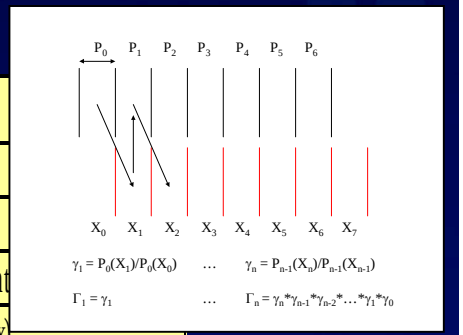


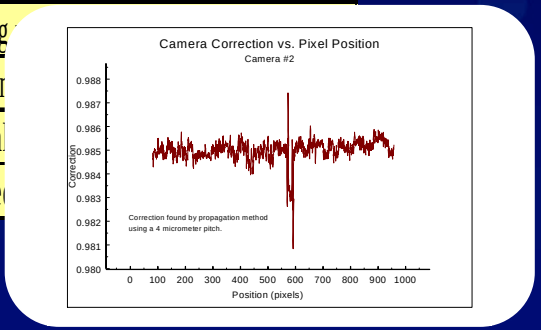
Photomask linewidth standard SRM 2059

Overlay Wafers SRM 5000

- The expanded uncertainty is comparable to industry level metrology tool performance.
- An array of targets and offsets for linearity calibration.
- Total uncertainty 2.5-3 nm 2δ
- Currently being used at IBM and SEMATECH to test production tools
  - Revealing….

Uncertainty Budget Components		OL < 63nm	OL < 125nm	
		1 sigma	1 sigma	
Component Description:	Unc. Type	a (nm)	a (nm)	Comment
1) Measurement Repeatability	A	-	-	Act St Dev's are used per target measurement
2) Scale Error	B	0.2	0.4	Derived from variation in scale factor (nm/pix)
3) Pixel Placement/Response Error	B	0.6	1.1	Worst case in region being
4) Parameter Variation Error	B	0.0	0.0	We believe this is a randor
5) TIS Correction Error + Other Optics	B	1.0	1.0	Conservative correction, a
6) Algorithm Target Bias Error	B	0.5	1.0	TIS-Corr Mean not affecte





An example of an expanded uncertainty from a NIST overlay calibration.

nanomanufacturing

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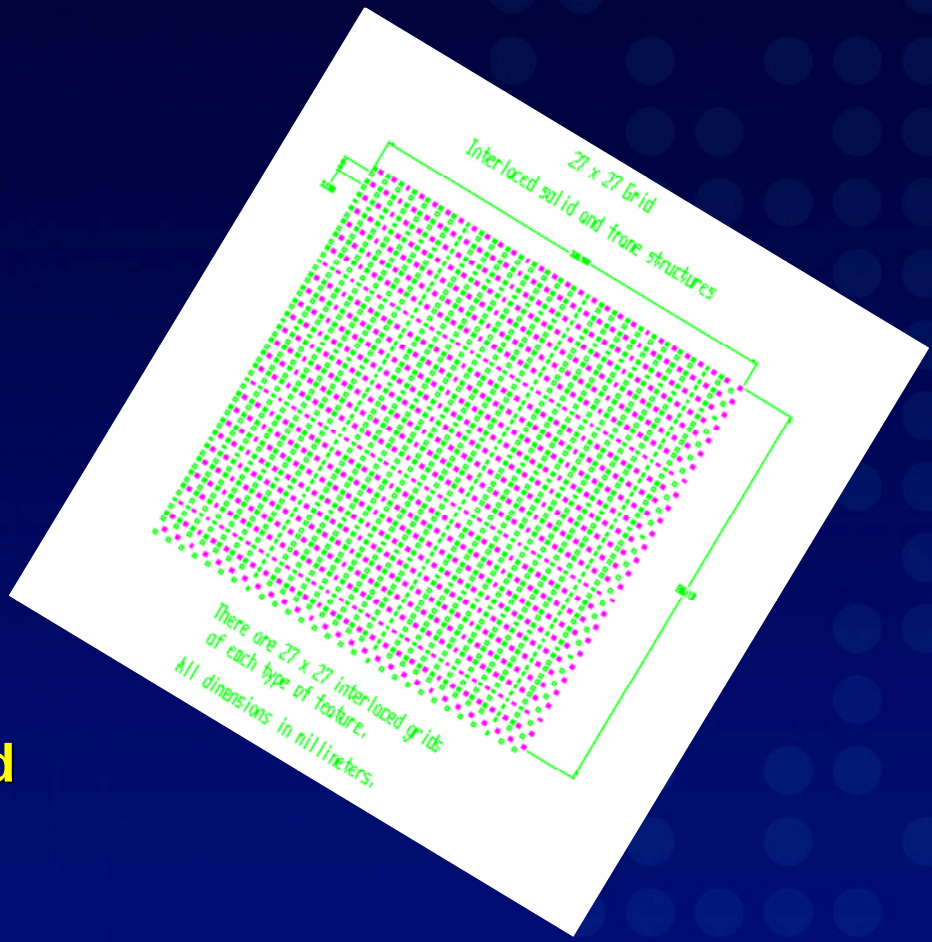
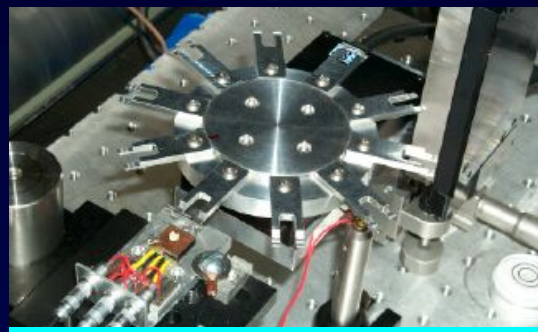
SRM 5001 2-dimensional Grid Standard

- Two-dimensional grid photomask standard with complete uncertainty analysis with world class leading uncertainty.
- SRM provides a traceable standard for the calibration of photomask positioning metrology tools as well as tools which require accurate placement of a wafer within the field of view.
- First time a photomask standard has been available for registration metrology.

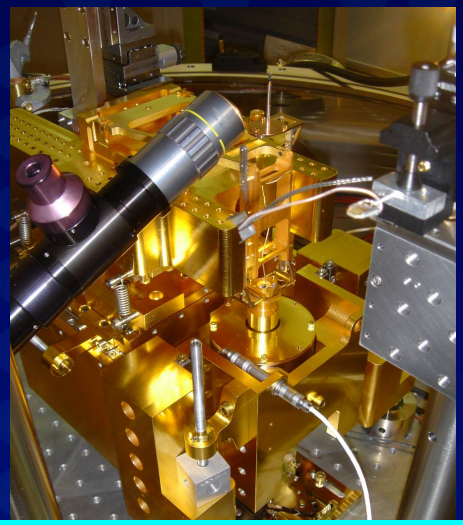


Project: Small Force Metrology

- **Provides SI traceability for small force measurement and instrumentation**
  - **–Atomic Force Microscopy**
  - **–Magnetic Storage Industry**
- **Successfully extended force measurements down to the nanonewton regime**



Traceable micro to millinewtons from NIST wire deadweight loader and modified Hysitron force cell



Traceable nano to micronewtons from NIST Electrostatic Force Balance

MEL Nanomanufacturing Program

- MEL Nanometrology Program is providing a "toolbox" to emerging nanomanufacturers for:
  - Measurement science, theory, modeling, simulation, standards and instrumentation for accurate measurements
  - Instrument control processes and standards
  - Nanofabrication and nanolithography
  - Measurement tools and standards for all aspects of nanotechnology

Strategic Alliances Imperative

- Developing effective nanometrology and nano-standards is not a simple problem to solve
- Success requires strategic alliances between: Governments, University and Industry
- Nanotech strong fit for strategic alliances
  - Multi-disciplinary nature
  - Enabling technology
  - Broad industry implications
  - Federal funding opportunities
  - Commercialization challenges
- Cannot be done alone which leads to the multidimensional nature of nanotechnology…
- ..and the reason for this workshop!


Thank you
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Contact Information

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The End